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Gary C. White
Department of Fishery and Wildlife
Colorado State University
Fort Collins, Colorado 80523

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Twenty-five quadrats in 2 strata were sampled (Table 1). Notation follows Thompson et al. (1998), so that U_h defines the number of quadrats in the sampling frame (units) for strata h, $h = 1, ..., L$ whereas u_h defines the number of quadrats sampled in strata h. U and u are used in place of the usual notation from sampling theory so that N can be reserved for the size of the biological population being estimated. For each quadrat, the number of owls estimated to be on the quadrat ($\hat{N}_{hi}$) was computed from a capture-recapture survey of the quadrat to estimate the resighting probabilities. These resighting probabilities were then used to correct the number of owls marked or otherwise known to be on the quadrat to obtain $\hat{N}_{hi}$.

Encounter data from banded owls from 11 quadrats (Table 2) were used to estimate resighting probabilities with Program MARK (White and Burnham 1999)and the Huggins closed captures data type (Huggins 1989, 1991). Specific models of owl gender, road access to the quadrat, time-specific encounter probabilities, and behavioral response to initial capture that were considered are listed in Table 3. Estimates of time-specific initial sighting probabilities (p_i) were model-averaged for the models considered using AIC weights as suggested by Burnham and Anderson (1998) and implemented in Program MARK.

To compute the estimate of population size from the initial sighting probabilities for each pass (p_i) estimated from the Huggins model, an overall probability of seeing an owl is estimated as

$$p^* = 1 - (1 - \hat{p}_1)(1 - \hat{p}_2)(1 - \hat{p}_3)(1 - \hat{p}_4).$$

For quadrats with only 3 passes, $\hat{p}_4 = 0$, and for quadrats with only 2 passes, $\hat{p}_3 = \hat{p}_4 = 0$. The population estimator is then $\hat{N}_i = \frac{M_{t+1,i}}{p^{*}_i}$, where i indexes quadrat and M_{t+1} is the number of owls banded on the quadrat. For the 50 quadrats sampled in the following analysis, 10 values of p^* are required because there are only 10 combinations of road access times number of passes times gender:

Index of $\hat{p}^*$	Access	Number of Passes	Gender	Representative Quadrat
1	Roaded	4	Male	H02
2	Roaded	3	Male	H16
3	Unroaded	2	Male	H18
4	Unroaded	3	Male	H21
5	Unroaded	4	Male	H22
6	Roaded	4	Female	H02
7	Roaded	3	Female	H16
8	Unroaded	2	Female	H18
9	Unroaded	3	Female	H21
10	Unroaded	4	Female	H22

These estimates of p^* were used to correct the number of owls banded plus the additional number of owls known to exist on the quadrat (but not banded) on each quadrat for their detection probability (Table 4). To compute the variance of the population estimate for each quadrat, the delta method was used. Define the estimated variance-covariance matrix of the 32 model-averaged estimates of the $\hat{p}_i$ values as $\hat{\mathrm{Var}}(\hat{\boldsymbol{p}})$ where bold terms represent matrices. The matrix $\hat{\mathrm{Var}}(\hat{\boldsymbol{p}})$ is output from the model averaging procedure of Program MARK. From this matrix, the $\hat{\mathrm{Var}}(\hat{\boldsymbol{p}}^*)$ is estimated as

$$\hat{\mathrm{Var}}(\hat{\boldsymbol{p}}^*) = \frac{\partial \boldsymbol{p}^{*T}}{\partial \boldsymbol{p}} \hat{\mathrm{Var}}(\hat{\boldsymbol{p}}) \frac{\partial \boldsymbol{p}^*}{\partial \boldsymbol{p}}$$

where T indicates the transpose of the matrix of partial derivatives. The matrix of partial derivatives is a 10×32 matrix, $\hat{\mathrm{Var}}(\hat{\boldsymbol{p}})$ is a 32×32 matrix from the model averaging procedure of Program MARK, so that $\hat{\mathrm{Var}}(\hat{\boldsymbol{p}}^*)$ is a 10×10 matrix.

To compute the variance-covariance matrix of the 50 estimates of male and female population size for each of the 25 quadrats in Table 4, $\hat{\mathrm{Var}}(\hat{\boldsymbol{p}}^*)$ was expanded to be a 50×50 matrix. For $\hat{\boldsymbol{N}}$, the 50×1 vector of estimated sex-specific population sizes,

$$\hat{\mathrm{Var}}(\hat{\boldsymbol{N}}) = \frac{\partial \boldsymbol{N}^{T}}{\partial \boldsymbol{p}^*} \hat{\mathrm{Var}}(\hat{\boldsymbol{p}}^*) \frac{\partial \boldsymbol{N}}{\partial \boldsymbol{p}^*}.$$

To compute the estimate of the total number of owls (males plus females) on the 25 quadrats, the matrix $\mathbf{A}$ is defined as consisting of 2 25×25 identity matrices set side-by-side. Then $\hat{\boldsymbol{N}}_{Total} = \boldsymbol{A}\hat{\boldsymbol{N}}\boldsymbol{A}^{T}$, where $\hat{\boldsymbol{N}}$ is a 50×1 vector and $\hat{\boldsymbol{N}}_{Total}$ is a 25×1 vector, with the

estimated variance-covariance matrix $\hat{\mathrm{Var}}(\hat{\boldsymbol{N}}_{\boldsymbol{Total}}) = \boldsymbol{A}\hat{\mathrm{Var}}(\hat{\boldsymbol{N}})\boldsymbol{A}^T$ (Table 5). To compute estimated density for each of the 25 quadrats, $\hat{\boldsymbol{D}} = \boldsymbol{B}\hat{\boldsymbol{N}}_{\boldsymbol{Total}}$, where the matrix $\boldsymbol{B}$ is a 25 × 25 diagonal matrix with diagonal elements consisting of the reciprocal of the area (km^{-2}) of each quadrat, with $\hat{\mathrm{Var}}(\hat{\boldsymbol{D}}) = \boldsymbol{B}\,\hat{\mathrm{Var}}(\hat{\boldsymbol{N}}_{\boldsymbol{Total}})\,\boldsymbol{B}^T$ (Table 5).

To compute the total population size for the recovery unit ($\hat{N}$), a ratio estimator was used following Cochran (1977) where the ratio of estimated population size ($\hat{N}_{hi}$ obtained from the $\hat{\boldsymbol{N}}_{\boldsymbol{Total}}$ vector) to quadrat area (a_{hi}, with A_h the area of the strata) is used:

$$\hat{N} = \sum_{h=1}^{L} \hat{N}_h = \sum_{h=1}^{L} \hat{R}_h A_h ,$$

where

$$\hat{R}_h = \frac{\sum_{i=1}^{n_h} \hat{N}_{hi}}{\sum_{i=1}^{n_h} a_{hi}} .$$

Because observed values on each quadrat are estimates instead of exact counts, and because of the covariances of the $\hat{N}_{hi}$ induced by estimating common resighting probabilities across quadrats and strata, the estimated variance of $\hat{N}$ [$\hat{\mathrm{var}}(\hat{N})$] is considerably more complicated than the usual case:

$$\begin{aligned}
\hat{\mathrm{var}}(\hat{N}) = {} & \sum_{h=1}^{L} U_h^2 \left(\frac{1}{u_h} - \frac{1}{U_h} \right) \sum_{i=1}^{u_h} \frac{\left(\hat{N}_{hi} - \hat{R}_h a_{hi} \right)^2}{u_h - 1} \\
& + \sum_{h=1}^{L} \frac{U_h^2}{u_h} \left[\sum_{i=1}^{u_h} \frac{\hat{\mathrm{var}}(\hat{N}_{hi})}{u_h} + \sum_{i \neq i'}^{u_h} \frac{\hat{\mathrm{cov}}(\hat{N}_{hi}, \hat{N}_{hi'})}{u_h} \right] \\
& + \sum_{h=1}^{L} \sum_{h \neq h'}^{L} \frac{U_h U_{h'}}{u_h u_{h'}} \sum_{i=1}^{u_h} \sum_{i'=1}^{u_{h'}} \hat{\mathrm{cov}}(\hat{N}_{hi}, \hat{N}_{h'i'}) \\
& - \sum_{h=1}^{L} U_h^2 \left(\frac{1}{u_h} - \frac{1}{U_h} \right) \left[\sum_{i=1}^{u_h} \frac{\hat{\mathrm{var}}(\hat{N}_{hi})}{u_h} - \sum_{i=1}^{u_h} \sum_{i' \neq i}^{u_h} \frac{\hat{\mathrm{cov}}(\hat{N}_{hi}), \hat{N}_{hi'})}{u_h (u_h - 1)} \right] .
\end{aligned}$$

A reasonable approximation to this equation where the finite population correction is ignored

and $u_h^2 \approx u_h(u_h - 1)$ is

$$\hat{\text{var}}(\hat{N}) = \sum_{h=1}^{L} \frac{U_h^2}{u_h}\left[\sum_{i=1}^{u_h} \frac{\left(\hat{N}_{hi} - \hat{R}_h a_{hi}\right)^2}{u_h - 1}\right]$$

$$+ \sum_{h=1}^{L} \frac{U_h^2}{u_h(u_h - 1)} \sum_{i=1}^{u_h} \sum_{i \neq i'}^{u_h} \hat{\text{cov}}(\hat{N}_{hi}, \hat{N}_{hi'})$$

$$+ \sum_{h \neq h'} \frac{U_h U_{h'}}{u_h u_{h'}} \sum_{i=1}^{u_h} \sum_{i'=1}^{u_{h'}} \hat{\text{cov}}(\hat{N}_{hi}, \hat{N}_{h'i'}) \quad .$$

These equations incorporate the covariances of the $\hat{N}_{hi}$ across quadrats and strata and thus are extensions of the formulae given by Skalski (1994).

The estimate of population size [$\hat{N} = 2996.5$, $\hat{\text{SE}}(\hat{N}) = 1136.2$] for the recovery unit had a coefficient of variation. (CV) equal to 38% (Table 6). Of interest is the estimate of the uncorrected number of owls for the recovery unit (naive estimate) computed with a ratio estimator of $\hat{N}$. The estimates for the high and low strata are 2126.4 (SE = 620.2) and 37.0 (SE = 79.5) respectively, giving a naive estimate of 2163.4 (SE = 625.3) for the recovery unit. The difference in the standard errors for the naive estimate and $\hat{N}$ are substantial, and point to the impact of quadrat H21 in particular, but also H22 and H18 to some extent, in greatly increasing the variance of the estimate when detection probability corrections were applied. These quadrats had some of the lowest detection probabilities, and hence much larger variances for $\hat{N}_{hi}$. These 3 quadrats contribute 99.6% of the variance to the term $\sum_{h=1}^{L} \sum_{i=1}^{u_h} \hat{\text{var}}(\hat{N}_{hi})$.

Power Analysis

The Mexican Spotted Owl Recovery Plan (USFWS 1995) requires that the Mexican Spotted Owl be shown to be stable or increasing for 10 years with a power of 90% to detect a decline of 20%. Two approaches were considered to meet the requirements of the Plan. First, a regression approach where annual population estimates are regressed with time was considered. In this approach, the rate of change of the population (λ) is estimated from the slope of the regression. Second, an approach where the rate of change of the population is estimated directly from the quadrat counts. The advantage of this approach is that the among quadrat variance of the population estimates is removed from the analysis, with the idea that there is less among quadrat variance of λ than of population size.

Regression Approach to Power Analysis

A 20% decline over 10 years means that the population would decrease by

$$1 - 0.8^{1/9} = 0.02449$$

per year. The power to detect this rate of decline was assessed with the methods given by Gerrodette (1987) as described by Thompson et al. (1998). A one-sided test with a sample of $n = 10$ years, $\alpha = 0.05$, and $r = -0.02449$ in the multiplicative model

$\ln(N_i) = N_1(1 + r)^{i-1} + \varepsilon_i$ was assumed with 3 error structures: CV_i proportional to $1/\sqrt{\hat{N}_i}$, constant, and $\sqrt{\hat{N}_i}$. Power as a function of the $CV(\hat{N})$ is shown in Figure 1 for each of the 3 error structures.

The clear conclusion is that the current level of effort is woefully inadequate to detect a 20% decline with 10 years of surveys. Even if the $\hat{N}_{hi}$ could be estimated with no error, the naive estimator based on the minimum number of owls known to be on a quadrat that this level of effort with the current stratification would be inadequate to obtain the necessary power, because the CV of this estimate is still 29%, still giving a power of <0.2.

To meet the requirements of the Recovery Plan, the CV of $\hat{N}$ must be about 7%. Several possibilities exist to improve the existing sampling plan. As noted above, there is considerable variance introduced into the estimate of $\hat{N}$ because of the low detection probabilities in 3 of the high density strata quadrats. Given the $CV(\hat{N}) = 38\%$, it would appear from comparisons with the naive estimator based on minimum number known alive that consistently high detection probabilities would lower this CV to about 30%.

Therefore, the main strategy for improving the sampling plan without increasing cost should be to improve the stratification scheme. The estimate for the low density strata is ideal, with a range 0-1 for owls located on the low density quadrats, and contributes little variance to the total. However, the high density strata had a range 0-17, suggesting improvements can be made. The large variance of $\hat{N}$ comes predominantly from the high variability across the high density quadrats. The variance of the mean of the 20 high-density quadrats for the minimum number known alive is 23.8/20, which when multiplied by $U_h^2 = 590^2 = 348100$ gives 414,239, or a SE of 644. This is the source of variation that is debilitating the effectiveness of the sampling plan.

The final alternative (although not very likely given the already large expense of this sampling plan) is to increase the sample size. Roughly a 10-fold increase would be required to obtain the necessary precision to detect a 20% decrease in 10 years, i.e., a $CV(\hat{N}) = 7\%$, for the naive estimates based on the minimum number known alive. Approximately an 18-fold increase would be required to obtain the necessary precision for the exact estimator of the variance of $\hat{N}$ when the current variability of detection probabilities is used.

Approach to Estimating λ Directly from Quadrat Data

Because the among quadrat variance is so high for estimates of $\hat{N}$, causing a large variance for any estimate of λ obtained by taking ratios of consecutive $\hat{N}$ values, an alternative approach has been considered. Estimation of λ can be made based on the sample, and then extrapolated to the population. To illustrate, consider the 20 values of N_{hi} for the high density strata (i.e., the owls observed on each quadrat, given in Table 5). Assuming a second survey in one year, an estimate of λ for the year from t to t+1 for strata h is:

$$\hat{\lambda}_t = \frac{\sum_{i=1}^{u_h} \hat{N}_{t+1,\,hi}}{\sum_{i=1}^{u_h} \hat{N}_{t,\,hi}}.$$

If survey techniques are changed so that few large standard errors for $\hat{N}_{hi}$ are made small, the standard errors of $\hat{N}_{hi}$ can be ignored. This was done by using the M_{t+1} values from Table 5 in place of $\hat{N}_{hi}$ in the following power calculation. The sampling variance of λ can be estimated by recognizing that $\hat{\lambda}$ is a simple ratio estimator (e.g. Cochran 1977:150-188). For a given strata h,

$$\hat{\text{var}}(\hat{\lambda}_t) = \frac{(1 - f)}{\frac{1}{u_h}\left(\sum_{i=1}^{u_h} \hat{N}_{t,\,hi}\right)^2} \frac{\sum_{i=1}^{u_h} (\hat{N}_{t+1,\,hi} - \hat{\lambda}\hat{N}_{t,\,hi})^2}{(u_h - 1)}$$

The overall estimate of λ across a 10-year period would consist of the product of the 9 $\hat{\lambda}$ values as calculated by the above formula. The variance of the λ estimate for the 10-year period can be obtained as the variance of the product of the 9 estimates by repeatedly applying the formula (Goodman 1960):

$$\hat{\text{var}}(xy) = x^2\hat{\text{var}}(y) + y^2\hat{\text{var}}(x) - \hat{\text{var}}(x)\hat{\text{var}}(y).$$

However, the product $\prod_{j=1}^{9} \hat{\lambda}_j$ is just the ratio estimator for the surveys at time $t = 1$ and $t = 10$, i.e.

$$\hat{\lambda} = \prod_{j=1}^{9} \hat{\lambda}_j = \frac{\sum_{i=1}^{u_h} \hat{N}_{t+9,\,hi}}{\sum_{i=1}^{u_h} \hat{N}_{t,\,hi}}$$

because the intermediate terms cancel out of the equation. Thus, the variance for the decline across 10 years is can be estimated as

$$\hat{\text{var}}(\hat{\lambda}_t) = \frac{(1 - f)}{\frac{1}{u_h}\left(\sum_{i=1}^{u_h} \hat{N}_{t,\,hi}\right)^2} \frac{\sum_{i=1}^{u_h} (\hat{N}_{t+9,\,hi} - \hat{\lambda}\hat{N}_{t,\,hi})^2}{(u_h - 1)}$$

For the following power analysis over a 10-year period, declines of 80% were simulated, (i.e., annual $\lambda = 0.80^{(1/9)}$. To incorporate demographic variation into the analysis, two sets of

population parameters were used to model annual rate of change of the population: set 1 had survival - emigration (φ) equal to 0.865089 and immigration + recruitment (f) equal to 0.110422, giving $\lambda = \varphi + f = 0.975511$; set 2 had $\varphi = 0.844752$ and $f = 0.1307591$ again giving $\lambda = 0.975511$. The parameter φ is the probability that an owl on the quadrat at time t remains alive and on the quadrat at time $t+1$. The parameter f is the probability that an owl on the quadrat at time t contributes an offspring or a new immigrant to the population at time $t+1$. These parameter sets were derived from demographic data from the NM and AZ study areas, from which a mean φ of 0.844752 and a mean f of 0.110422 were estimated. These values were adjusted to obtain parameter sets 1 and 2 to give a rate of change across 10 years of exactly 80%. Once a quadrat reached a zero population level, the re-colonization probability was zero, i.e., quadrats never experienced immigration unless at least one animal was present. Demographic variation was modeled as a random binomial variable. Thus the population size on a quadrat at time $t+1$ was computed as the random binomial variable of the owls surviving from time t plus another random binomial variable of the number of new immigrants and recruits since time t. Numbers of quadrats were taken as 25, 40, 50, 60, 75, 100, 125, 150, 175, and 200. Estimates of β where $\beta = 1$ - power were computed by determining the proportion of confidence intervals on the estimate of λ for the 9-year product that covered 1. For each sample size, 100,000 simulations were conducted to estimate power. Results are shown in Figure 2. A design with power >0.9 is achieved if between 100 and 150 quadrats are sampled in year 1 and resampled in year 10. Additional power analyses have demonstrated that sampling during the intervening years (2-9) does not increase the power of this design. That is, the temporal variation of the process does not affect the power of the survey to detect an 80% decline, i.e., temporal variation does not affect the sampling variance of the estimated population change. Rather, temporal variation in the population growth process just affects the probability that the population will decline by 80%.

Conclusions

A survey design that will meet the power requirements of the Recovery Plan only requires the same randomly selected quadrats to be sampled in years 1 and 10. The number of quadrats to be sampled is between 100 and 125, with my recommendation to take a sample of 125 quadrats the first year to allow for attrition. Given the costs accrued during the pilot survey, a sample of 125 quadrats would cost approximately $5M in year 1, with a similar cost plus inflation for year 10.

Table 1. Distribution of quadrats and characteristics of the two strata used to estimate the population size of Mexican Spotted Owls in the Upper Gila Recovery Unit.

Strata (h)	Strata Area (A_h) (km^2)	Area Sampled $\left(\sum_{i=1}^{u_h} a_h\right)$ (km^2)	Total Quadrats (U_h)	Quadrats Sampled (u_h)
Low	10,046.39	271.81	390	5
High	35,384.26	1,231.40	593	20
Total	45,432.65	1,505.21	983	25

Table 2. Mexican Spotted Owl quadrats from the Upper Gila Recovery Unit used to estimate resighting probabilities in Program MARK.

Quadrat	Number of Marked Owls		Number of Passes	Road Access
	Males	Females		
H02	3	3	4	Roaded
H04	1	1	4	Roaded
H08	1	0	4	Roaded
H16	4	3	3	Roaded
H17	1	1	4	Roaded
H18	1	2	2	Unroaded
H20	1	0	4	Roaded
H21	4	4	3	Unroaded
H22	2	2	4	Unroaded
H23	3	2	4	Roaded
H24	5	5	4	Roaded

Table 3. List of models considered in Program MARK for estimating Mexican Spotted Owl sighting probabilities from quadrats listed in Table 1, and resulting summary statistics, including the AIC weights used for model averaging.

Model	AICc	Delta AICc	AICc Weight	#Par	Deviance
{p(T+Roadless+Sex)=c(T+Roadless+Sex), 0 passes}	221.617	0.00	0.40910	4	213.412
{p(T*Roadless+Sex)=c(T*Roadless+Sex), 0 passes}	222.987	1.37	0.20622	5	212.677
{p(T+Roadless+Sex)=c(T+Roadless+Sex)+const, 0 passes}	223.618	2.00	0.15042	5	213.308
{p(T+Roadless*Sex)=c(T+Roadless*Sex), 0 passes}	223.680	2.06	0.14583	5	213.371
{p(T+Roadless)=c(T+Roadless)+const, 0 passes}	227.751	6.13	0.01905	4	219.546
{p(Roadless) c(Roadless), 0 passes}	228.366	6.75	0.01401	4	220.160
{p(.) c(Roadless), 0 passes}	228.637	7.02	0.01223	3	222.514
{p(T+Roadless+Sex) c(T+Roadless+Sex) 0 passes}	229.488	7.87	0.00799	8	212.734
{p(Roadless)=c(Roadless), 0 passes}	229.741	8.12	0.00704	2	225.681
{p(T+Sex)=c(T+Sex), 0 passes}	229.748	8.13	0.00702	3	223.625
{p(Sex) c(Sex), 0 passes}	230.209	8.59	0.00557	4	222.004
{p(T*Sex)=c(T*Sex), 0 passes}	231.405	9.79	0.00306	4	223.199
{p(T+Sex)=c(T+Sex)+const, 0 passes}	231.624	10.01	0.00275	4	223.419
{p(Roadless Continuous)=c(Roadless Continuous), 0 passes}	231.756	10.14	0.00257	2	227.695
{p(Sex)=c(Sex), 0 passes}	232.225	10.61	0.00203	2	228.164
{p(T*Sex)=c(T*Sex)+const, 0 passes}	233.246	11.63	0.00122	5	222.936
{p(t+Sex)=c(t+Sex), 0 passes}	233.495	11.88	0.00108	5	223.185
{p(Roadless) c(.), 0 passes}	233.497	11.88	0.00108	3	227.374
{p(.) c(.), 0 passes}	233.789	12.17	0.00093	2	229.728
{p(T)=c(T)+const, 0 passes}	235.700	14.08	0.00036	3	229.578
{p(.)=c(.), 0 passes}	236.771	15.15	0.00021	1	234.751
{p(t)=c(t), 0 passes}	238.112	16.50	0.00011	4	229.907
{p(Quadrat)=c(Quadrat), 0 passes}	239.381	17.76	0.00006	11	215.977
{p(t*Sex)=c(t*Sex), 0 passes}	239.411	17.79	0.00006	8	222.657
{p(Quadrat) c(Quadrat), 0 passes}	247.588	25.97	0.00000	22	197.871
{p(.)=c(.)}	268.568	46.95	0.00000	1	266.548

Table 4. List of 25 Mexican Spotted Owl quadrats surveyed in the Upper Gila Recovery, with separate estimates of population size for males and females on each quadrat..

Quadrat	Sex	Banded	Unbanded	p^* Index	$\hat{p}^*$	$\hat{N}$	SE($\hat{N}$)	Comment
H01	Male	0	0	1	0.9854	0	0	
H02	Male	3	0	1	0.9854	3.04445	0.0397	
H03	Male	0	0	1	0.9854	0	0	
H04	Male	1	0	1	0.9854	1.01482	0.0132	
H07	Male	0	1	1	0.9854	1.01482	0.0132	daytime observation
H08	Male	1	0	1	0.9854	1.01482	0.0132	
H09	Male	0	0	1	0.9854	0	0	
H11	Male	0	0	1	0.9854	0	0	
H12	Male	0	1	1	0.9854	1.01482	0.0132	nesting pair observed
H13	Male	0	1	1	0.9854	1.01482	0.0132	nesting pair observed
H14	Male	0	0	1	0.9854	0	0	
H16	Male	4	0	2	0.9691	4.12754	0.0927	
H17	Male	1	0	1	0.9854	1.01482	0.0132	
H18	Male	1	1	3	0.5792	3.45304	1.1296	
H19	Male	0	0	1	0.9854	0	0	
H20	Male	1	0	1	0.9854	1.01482	0.0132	
H21	Male	4	5	4	0.6916	13.0133	3.6373	unbanded mate; pair observed; inferred from young/mate
H22	Male	2	1	5	0.7599	3.94789	0.9870	mate of pair
H23	Male	3	0	1	0.9854	3.04445	0.0397	
H24	Male	5	3	1	0.9854	8.11853	0.1059	mate of pair; daytime observation
L01	Male	0	0	1	0.9854	0	0	
L02	Male	0	0	1	0.9854	0	0	
L03	Male	0	0	1	0.9854	0	0	
L05	Male	0	0	5	0.7599	0	0	
L06	Male	0	0	1	0.9854	0	0	

Quadrat	Sex	Banded	Unbanded	p^*	Index	$\hat{p}^*$	$\hat{N}$	SE($\hat{N}$)	Comment
H01	Female	0	0		6	0.8990	0	0	
H02	Female	3	0		6	0.8990	3.33704	0.2811	
H03	Female	0	0		6	0.8990	0	0	
H04	Female	1	0		6	0.8990	1.11235	0.0937	
H07	Female	0	0		6	0.8990	0	0	
H08	Female	0	1		6	0.8990	1.11235	0.0937	mate of nesting pair
H09	Female	0	0		6	0.8990	0	0	
H11	Female	0	0		6	0.8990	0	0	
H12	Female	0	1		6	0.8990	1.11235	0.0937	nesting pair observed
H13	Female	0	1		6	0.8990	1.11235	0.0937	nesting pair observed
H14	Female	0	0		6	0.8990	0	0	
H16	Female	3	1		7	0.85234	4.69296	0.4847	mate of nesting pair
H17	Female	1	0		6	0.8990	1.11235	0.0937	
H18	Female	2	0		8	0.3299	6.06244	3.5058	mate of nesting pair
H19	Female	0	0		6	0.8990	0	0	
H20	Female	0	0		6	0.8990	0	0	
H21	Female	4	4		9	0.4196	19.0658	10.4453	unbanded mate; pair observed; inferred from young/mate
H22	Female	2	2		10	0.48399	8.26463	4.3877	mate of pair; daytime observation
H23	Female	2	0		6	0.8990	2.22469	0.1873	
H24	Female	5	2		6	0.8990	7.78643	0.6558	mate of pair
L01	Female	0	0		6	0.8990	0	0	
L02	Female	0	0		6	0.8990	0	0	
L03	Female	0	0		6	0.8990	0	0	
L05	Female	0	0		10	0.48399	0	0	
L06	Female	0	1		6	0.8990	1.11235	0.0937	daytime observation

Table 5. Estimated total population size (males and females combined) for each of the 25 quadrats surveyed.

Quadrat	Area (a_{hi}) (km^2)	Owls Observed (M_{t+1})	Estimated Population ($\hat{N}_{hi}$)	$\hat{SE}(\hat{N}_{hi})$	Estimated Density ($\hat{D}_{hi}$)	$\hat{SE}(\hat{D}_{hi})$
H01	43.68	0	0.00	0.00	0.00	0.00
H02	61.15	6	6.38	0.29	0.10	0.00
H03	46.45	0	0.00	0.00	0.00	0.00
H04	76.40	2	2.13	0.10	0.03	0.00
H07	59.60	1	1.01	0.01	0.02	0.00
H08	55.66	2	2.13	0.10	0.04	0.00
H09	54.88	0	0.00	0.00	0.00	0.00
H11	57.92	0	0.00	0.00	0.00	0.00
H12	63.20	2	2.13	0.10	0.03	0.00
H13	66.77	2	2.13	0.10	0.03	0.00
H14	68.09	0	0.00	0.00	0.00	0.00
H16	69.03	8	8.82	0.52	0.13	0.01
H17	62.32	2	2.13	0.10	0.03	0.00
H18	66.86	4	9.52	4.35	0.14	0.07
H19	49.94	0	0.00	0.00	0.00	0.00
H20	71.01	1	1.01	0.01	0.01	0.00
H21	72.80	17	32.08	13.16	0.44	0.18
H22	52.45	7	12.21	5.10	0.23	0.10
H23	66.26	5	5.27	0.20	0.08	0.00
H24	66.93	15	15.90	0.69	0.24	0.01
L01	40.89	0	0.00	0.00	0.00	0.00
L02	66.14	0	0.00	0.00	0.00	0.00
L03	68.53	0	0.00	0.00	0.00	0.00
L05	44.97	0	0.00	0.00	0.00	0.00
L06	51.28	1	1.11	0.10	0.02	0.00

Table 6. Results of estimating the density and population size for the low and high density strata in the Upper Gila Recovery Unit.

Strata	Strata Population ($\hat{N}$)	$\widehat{SE}(\hat{N})$	CV
High	2955.4	1131.0	38.3%
Low	41.1	87.9	213.9%
Recovery Unit without Tribal Lands	2996.5	1136.2	37.9%

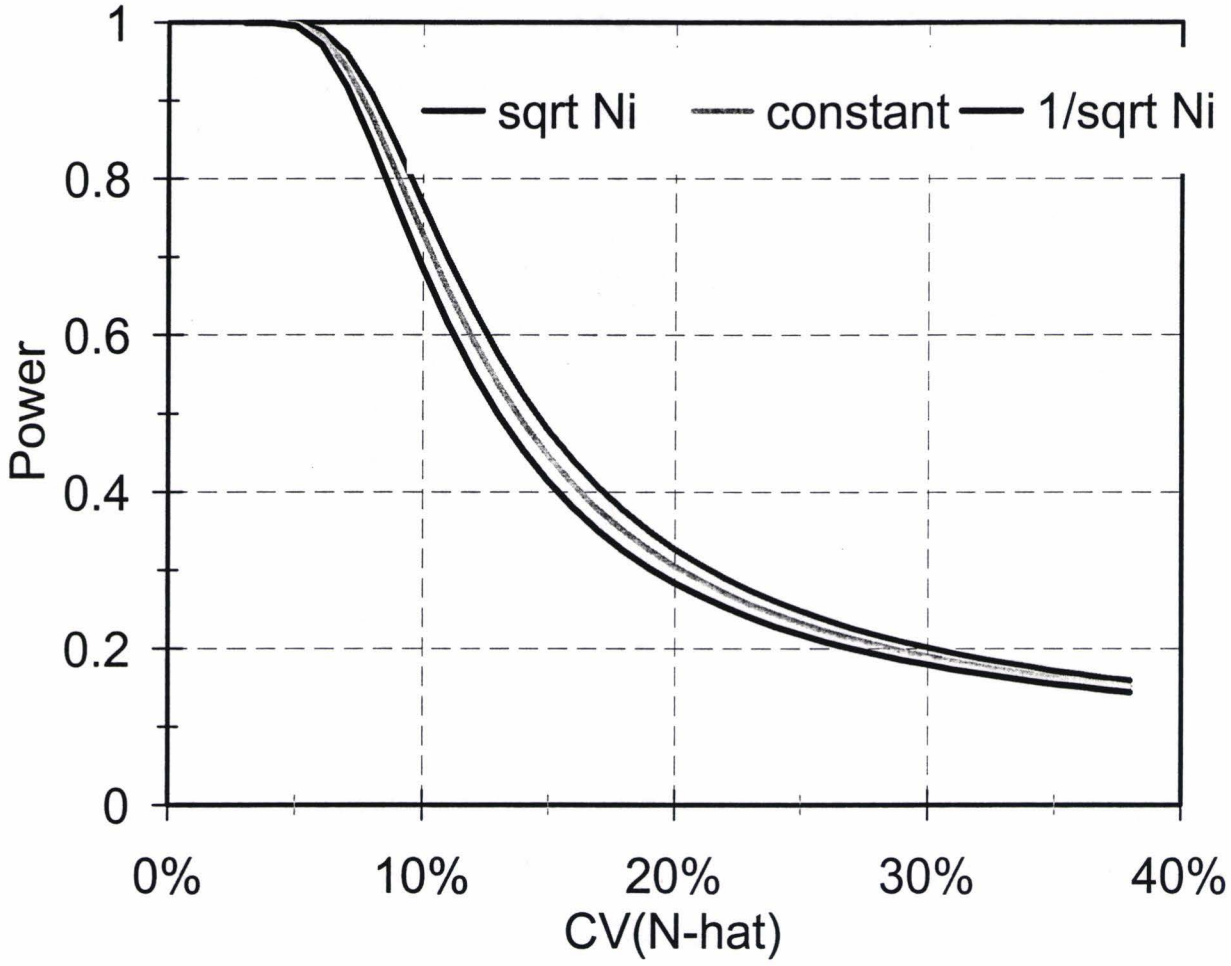

Figure 1. Estimated power to detect a 20% decline over 10 years with a power of 90% for $\alpha = 0.05$ as a function of CV($\hat{N}$).

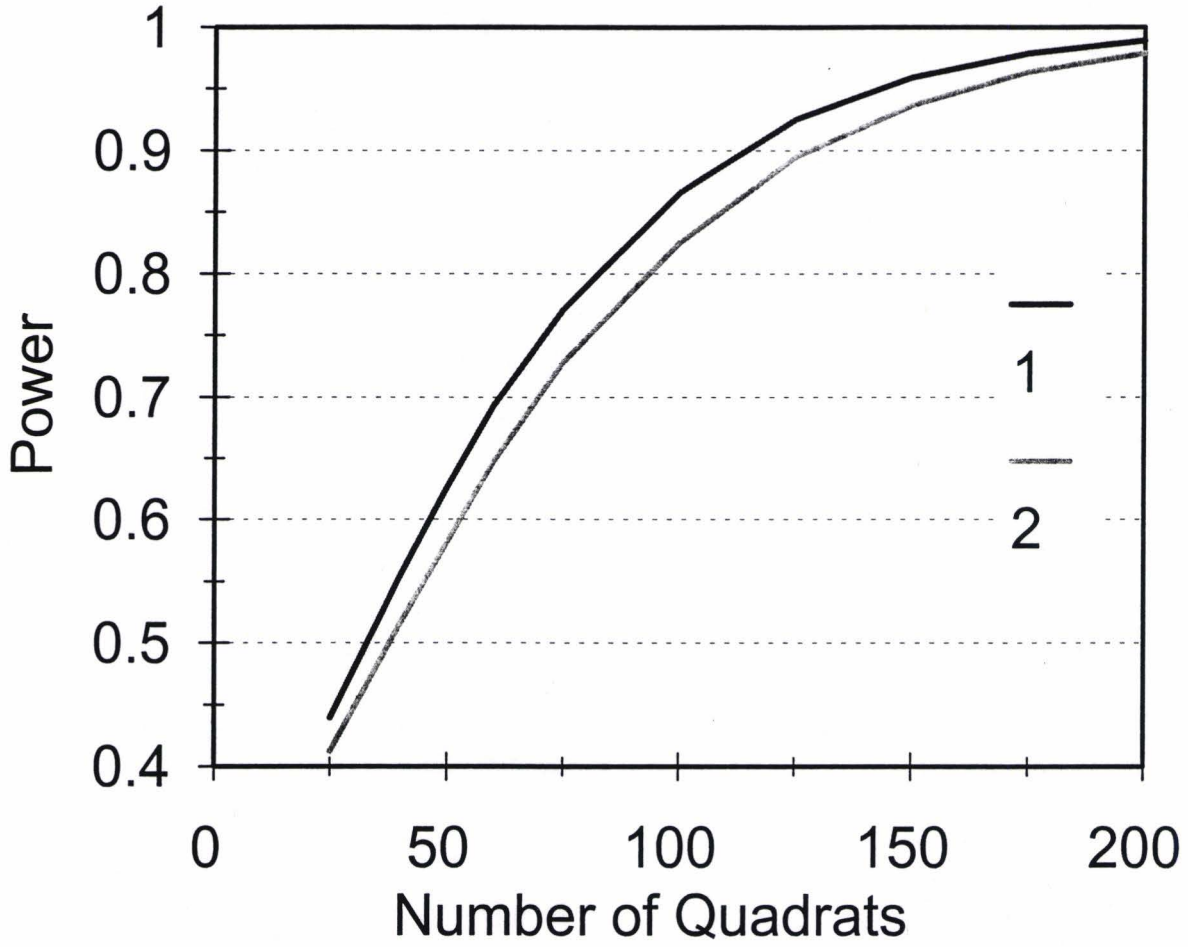

Figure 2. Power to detect a decline of 80% over a 10-year period when randomly selected quadrats are sampled in only years 1 and 10. Two sets of population parameters were used to model annual rate of change of the population: set 1 had survival - emigration (φ) equal to 0.865089 and immigration + recruitment (f) equal to 0.110422, giving an annual $\lambda = \varphi + f = 0.975511$ and a 10-year of $\lambda = 0.8$; set 2 had $\varphi = 0.844752$ and $f = 0.1307591$ again giving $\lambda = 0.975511$ and a 10-year of $\lambda = 0.8$.

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David Bowden, Department of Statistics, Colorado State University, derived the variance estimators for $\hat{N}$, no small accomplishment. Dr. Bowden also suggested use of the ratio estimator for estimating the sampling variance of $\hat{\lambda}$. Alan Franklin and Joe Ganey provided sounding boards that kept the direction of this report towards the goal of meeting the requirements of the Recovery Plan.

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